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ABSTRACT

This paper proposes a conceptual framework for evaluating the costs of projects to reduce atmospheric greenhouse gases (GHGs). The evaluation of cost-effectiveness should account for both the timing of carbon emissions and the damage caused by the atmospheric stock of carbon. We develop a conceptual basis to estimate the cost-effectiveness of projects in terms of the cost of reducing atmospheric carbon (CRAC) and other GHGs. CRAC accounts for the economic discount rate, alternative functional forms of the shadow price, the residence period of carbon in the atmosphere, and the multiple monetary benefits of projects. The last item is of particular importance to the developing countries.

The paper comments on the appropriate discount rates which should be used for evaluation of a project's carbon flows. We suggest that this rate be different and lower than that used to evaluate monetary costs and benefits.

The CRAC indicator may be used to rank projects to reduce atmospheric carbon. Projects with increasing CRAC may be pursued until a limit is reached. This limit may be defined by emissions stabilization goals or by the availability of funds for carbon reduction. The CRAC indicator is sensitive to the future shadow price of carbon. The future shadow price should be determined prior to the ranking of projects for implementation.

1 Introduction:

The concern regarding potential climatic changes due to the accumulation of greenhouse gases in the atmosphere has led to many studies of the phenomenon. The studies have focused on inventories of emissions, climate change models, and other physical processes. Economic studies of emissions abatement have largely restricted their scope to examining cost of abating emissions from energy sources. Most of these studies target industrialized countries; economic studies of emissions abatement for the developing countries are few.[1,2]

A recent paper has explored the potential for using forestry as a means to sequester carbon in order to reduce the growth of emissions from India.[3] The paper estimates that by 2005, strong afforestation programs could offset 17% of the energy emissions, with the potential to offset an even larger amount of India's carbon emissions beyond that year.

But would such afforestation be cost-effective, and how would it compare with other carbon reduction strategies like energy efficiency or fuel switching? What role do the discount and atmospheric decay rates play in ranking projects? Should the ranking be based on emissions or atmospheric carbon concentrations? Given the variety of economic frameworks (e.g., cost benefit analysis, social welfare analysis) for comparing the costs of restraining GHG emissions, which should govern climate policy? How do different functional forms of the shadow price of carbon affect a project's cost-effectiveness?

Howarth and Monahan (1992)[4] discuss three approaches to evaluate the economics of abatement: Cost-benefit analysis, social welfare analysis and the principle of sustainable development. They cite several advantages and disadvantages of each approach. Thus far, cost-benefit analysis is the only approach that has been widely used in economic evaluation of projects and policy options. Despite its short-comings, it offers an important tool for evaluating response options to climate change.

Currently, there is neither a market nor a "price" associated with greenhouse gas emissions. As such, the shadow price is used as a surrogate measure. The shadow price associated with greenhouse gas emissions represents society's marginal willingness to pay to prevent the release of an additional unit of pollution into the atmosphere. Since global warming impacts are intertemporal, willingness to pay includes the concern of current generations for the welfare of future generations.

This definition of shadow price has been used by other authors in evaluating the potential benefits of reducing carbon emissions. For example, Eckaus (1992)[5] uses this concept to define the emissions opportunity cost (EOC). The EOC is used to compare the effects of greenhouse gas emissions on global warming. Eckaus argues that the Global Warming Potential (GWP) is not a satisfactory policy tool since it does not adequately address economic issues. The definition of cost-effectiveness in this paper is based on a similar evaluation of shadow prices, shadow benefits and costs.

The shadow price of emissions will vary depending on the goal of climate policy as determined by the international community. Howarth, Monahan and Sathaye (1993)[6] derive formulas for the shadow prices of emissions using three alternative goals: Economic efficiency (derived through benefit-cost analysis), emissions reduction targets, and minimizing long-term stock accumulation. Their review of cost-benefit analysis assumed a particular damage function could be derived whereby future impacts from climate change could be monetized, discounted, and aggregated.

Deriving a damage function, given the uncertain and intertemporal nature of climate change, is likely an impossible task. The monetary values of potential impacts from climate change are obscured by issues of uncertainty, asymmetrical impacts, irreversibility, and unknown but potentially catastrophic outcomes (Howarth and Monahan, 1992). Given the elusiveness of a damage function and the necessity for evaluating alternative carbon-abatement projects, we apply the net-present value methodology to account for carbon emissions. In other words, this approach estimates cost-effectiveness in terms of the <u>present equivalence of future GHGs in the atmosphere.</u> The cost-effectiveness of a project varies with the changes in the shadow price over time. The approach is applicable to projects from all sectors, including energy, forestry, and agriculture, that have carbon emissions or sequestrations associated with them. It can be extended to cover other greenhouse gases like nitrous oxide and methane (see Appendix A).

We propose a framework to evaluate the cost-effectiveness of various carbon abatement projects, so each can be ranked with respect to its carbon emissions or sequestrations.[d] Projects that provide the maximum net benefit per unit of carbon sequestered, while meeting society's desired demand for energy services and/or biomass products in a particular year, would be ranked at the top. Those with highest cost per unit of emissions would be ranked at the bottom. Estimating the demand for these services and identifying which projects the country would have implemented as a base case will define the incremental costs of carbon reduction. Indeed, incremental costs may turn out to be negative if the country were to follow an energy efficient

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[d] Afforestation projects sequester carbon, while carbon efficiency measures limit GHG emissions. Carbon efficiency measures include various options to improve energy efficiency and to switch to less-carbon-intensive fuels.

scenario rather than an extrapolation of current-trends one (Mongia, Bhatia, Sathaye and Mongia (1991, Sathaye and Reddy, (1992)). King (1993)[7] and Anderson and Williams (1993)[8] have explored several other issues related to the estimation of incremental costs (see also the GEF Draft Analytical Framework for the Reduction of Net Greenhouse Gas Emissions.)

What discount rate should be used to evaluate the monetizable benefits and the carbon flows? Should these be identical? To what extent should the discount rate be influenced by the source of capital? How do considerations of equity affect the discount rate? The last issue is particularly important, and we dwell on it later.

This paper first presents a conceptual framework for estimating the cost-effectiveness of projects for reducing atmospheric carbon. We explain the framework using an illustrative example. This is followed by a discussion of the choice of discount rate(s) to account for monetary and carbon flows. Finally, we provide a summary, and conclusions of the paper.

1.1 Current Approach to Measuring Cost-Effectiveness:

In order to estimate the cost of conserved carbon emissions (CCCE), the cost of carbon reduction has been compared with the associated emissions reduction according to the formula[9]:

$$CCCE - NPV / \sum_{o}^{Te} C_t \tag{1}$$

NPV is the present value of net benefits and C_t is the amount of emissions reduced in period t. For an energy conservation project with no auxilliary benefits, NPV is the up front capital investment.

Whether the carbon is sequestered 10 years from now or today, the amount of carbon in the denominator is constant; only the numerator changes. There are two conceptual limitations with this approach for quantifying carbon reduction. First, we must recognize that the timing of carbon reduction is relevant to the analysis. The reduction of carbon represents damages avoided due to global warming; in other words, the carbon reduction can be considered a surrogate for the damages that would otherwise occur.

The second problem with the traditional means of accounting for sequestered carbon is conceptual. Since carbon remains in the atmosphere for a long period, it is important to consider the avoided atmospheric carbon and not the emissions per se in evaluating the cost-effectiveness of a project. Our proposed approach accounts for the timing of emissions and for the atmospheric stock of carbon.

2. Shadow Price of Carbon and Project Cost-Effectiveness

In this section, we derive an expression to compute a project's cost-effectiveness in terms of the shadow price of carbon. We compare this expression with earlier approaches to compute the cost-effectiveness of projects to reduce carbon emissions, and discuss the merits of our approach. The methodology for estimating the cost-effectiveness of inert and reactive greenhouse gases is illustrated in Appendix A.

Different approaches may be used to compare the benefits and costs of projects which have associated carbon flows. One approach would be to explicitly value the project costs and benefits, including carbon. However, evaluation of impacts or benefits, is beyond the realm of our current understanding of the damages that may be incurred by higher atmospheric concentration of carbon. Another approach would be to evaluate the cost-effectiveness of each project, where the monetizable costs and benefits would be evaluated separately from the stream of carbon emissions or sequestrations.

The evaluation of cost-effectiveness of a project with respect to its carbon implications needs to address two important issues. The first is the long duration of carbon in the atmosphere, where it has the potential to cause damage over many decades. The second is the timing of carbon flows from the project. Since the shadow price of carbon may change in the future, the value of reducing carbon emissions will vary depending on their time of release. So, if the shadow price were to increase sharply, then projects to reduce or sequester atmospheric carbon in the long term would be more desirable. On the other hand, a declining shadow price would favor projects to reduce emissions in the near future. To capture the consequences of the timing of carbon flows and the atmospheric stock of carbon, we derive an expression for evaluating a project's cost-effectiveness which is sensitive to changes in each variable.

2.1 Project Cost-Effectiveness for A Constant Shadow Price of Carbon:

2.1.1 Single Year Emissions:

Assume that we have a project with a one year lifetime that yields C_0 units of carbon emissions with no auxiliary benefits, and that society is willing to pay a price (shadow price), which may vary over time, for avoiding this carbon. (Alternatively, the project may sequester C_0 of carbon in the first year.) The carbon is emitted in the first year of the project and remains in the atmosphere for an indefinite period.[e] The shadow benefit, associated with the shadow price, can be expressed in terms of the single year emissions $\mathbf{C_0}$, shadow price of avoided carbon, $\mathbf{P_c}$(t), and discount rate **r**, and is the integral of this function

$$\textit{Shadow Benefit} \quad \int_0^\infty P_c(t)\, e^{-rt}\, C_0\, dt \tag{2}$$

Carbon in the atmosphere decays at some rate, **a**. The decay rate depends on a complex dynamic system of reservoirs, sinks and sources, and will probably change over time. With the saturation of the carbon sink capacity of the oceans, the decay rate will decline in the future. The IPCC 1990 report[10] estimates that the lifetime of carbon dioxide will increase linearly from 120 to 300 years over a 250 year period. Since our purpose here is to be able to rank projects implemented within relatively close time periods, we assume that the decay rate is a constant. Inclusion of this decay rate in equation (2) results in the following expression:

$$\textit{Shadow Benefit} = \int_0^\infty P_c(t)\, e^{-rt}\, C_0\, e^{-at}\, dt \tag{3}$$

Such a project is cost-effective if the investment **K** is less than or equal to the project shadow benefit.

$$K \leq \textit{Shadow Benefit} = \int_0^\infty P_c(t)\, e^{-rt}\, C_0\, e^{-at}\, dt \tag{4}$$

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[e] The IPCC has estimated a period of 120 years for carbon in the atmosphere. For the economic evaluation of projects this period is long enough to be treated as infinite. Treating the period as infinity simplifies the presentation, without significantly affecting the cost-effectiveness values.

The shadow price $\mathbf{P}_c(t)$ may vary over time and is a function of the stock of carbon in the atmosphere in a particular time period and the cost of reducing carbon emissions. We assume that the emissions, C_0, are negligibly small compared to the stock of atmospheric carbon. This assumption implies that the shadow price is not influenced by emissions from the project under consideration.

For algebraic simplicity, we will assume a constant shadow price over time for carbon. [Later, we will illustrate the impact of changes in shadow price over time (different functional forms) on the cost-effectiveness of a project.] Equation 4 may be rearranged in terms of the shadow price $\mathbf{P}_c$

$$P_c \geq K \ / \ (C_0 \int_0^\infty e^{-(r+a)t} \, dt) \tag{5}$$

The right hand side of equation 5 expresses the cost-effectiveness of the project. It represents the present value cost of reducing one unit of atmospheric carbon (CRAC).

$$CRAC = K \ / \ (C_0 \int_0^\infty e^{-(r+a)t} \, dt) \tag{6}$$

If CRAC $< P_c$, then the project is cost-effective. If CRAC $> P_c$, then the unit cost exceeds the shadow price, and the project may not be worth pursuing.

The numerator of equation 6 represents the present value of the project cost. The denominator is a surrogate for the damage caused by carbon stock, and represents the present value of the avoided cost, or the benefit. For a given discount and decay rate, the integral term in the denominator is a constant. It converts the damage caused by carbon stock into its present equivalent, and may be denoted as the present equivalent of atmospheric carbon or the <u>present carbon equivalent (PCE)</u>.

$$PCE = \int_0^\infty e^{-(r+a)t} \, dt = \frac{1}{(r+a)} \tag{7}$$

A developing country is unlikely to pursue a project whose sole benefit is to sequester carbon. Generally, a project which has multiple benefits is more likely to be implemented. In such an instance, the capital investment has other associated benefits and costs. These other benefits and costs can be captured by estimating the net present value of the project, devoid of the carbon benefit. The investment **K** in the above equations can be substituted by the net present value (NPV) of these monetizable benefits. Substituting NPV for K, a project's cost-effectiveness may be expressed as

$$CRAC = NPV/(C_0\ PCE) \tag{8}$$

where NPV = Net present value of monetizable benefits

C_0 represents the **net** emissions for a project which both emits and sequesters carbon.

2.1.2 Multiple Year Emissions:

For a project, with a series of annual net emissions, to be cost effective, the investment **K** has to be less than or equal to the shadow benefit, which may be expressed as

$$\begin{aligned} K \leq Shadow\ Benefit &= \int_0^\infty P_c\, e^{-rt}\, C_0\, e^{-at}\, dt + \frac{1}{(1+r)}\int_0^\infty P_c\, e^{-rt}\, C_1\, e^{-at}\, dt + \ldots \\ &= P_c\, C_0 \int_o^\infty e^{-(r+a)t} dt + \frac{P_c\, C_1}{(r+1)} \int_o^\infty e^{-(r+a)t} dt + \ldots \\ &= P_c\, (C_0 + \frac{C_1}{(r+1)} + \ldots)\ PCE \\ &= P_c\ PCE \sum_o^{Te} C_t\ /\ (1+r)^t \end{aligned} \tag{9}$$

Equation 9 computes the PCE for emissions in each time period t, which are discounted to the initial period. Summing over the present carbon equivalent of emissions or sequestrations over time 0 to T_e yields the atmospheric carbon equivalent for the project. For biomass projects, the period T_e may be longer than the project life since biomass decomposition may continue for some years even after the project has ended.

Substituting **NPV** for **K**, the CRAC may then be expressed as

$$CRAC = NPV\ /\ (PCE \sum_0^{Te} C_t\ /(1+r)^t) \tag{10}$$

where C_t = Net carbon emissions in time t

T_e = Time period over which net emissions occur.

Since access to, and availability of, capital is often a barrier to the implementation of projects in the developing countries, it is important to evaluate investment requirements in addition to the NPV of a project. In addition to estimating the total investment needs, the capital cost of reducing atmospheric carbon (CCRAC) may be computed by substituting investment, **K**, for NPV in the above equation.

$$CCRAC = K \,/\, (PCE \textstyle\sum_0^{Te} C_t \,/ (1+r)^t) \tag{11}$$

The investment, **K**, may be adjusted to reflect the relative scarcity of capital. Other cost components, such as foreign exchange, may be evaluated in terms similar to those for investment.

When two alternative projects are being considered to satisfy the same end-use, the incremental unit cost (IUC) of project A compared to B may be expressed as:

$$IUC = (NPVA - NPVB) \,/\, (PCE(\textstyle\sum_0^{T_A} CA_t \,/ (1+r)^t - \textstyle\sum_0^{T_B} CB_t \,/ (1+r)^t)) \tag{12}$$

NPVA and CA = Net present monetary value and carbon emissions of project A
NPVB and CB = Net present monetary value and carbon emissions of project B

2.2 Shadow Price Functional Form and Cost-Effectiveness:

The expression for cost-effectiveness is sensitive to the functional form of the shadow price over time. Above, we derived the CRAC assuming the shadow price remains constant over time. Below we derive the CRAC for two alternative functional forms of the shadow price. The first assumes that the future shadow price increases exponentially at the discount rate **r**, and the second that it increases at a higher rate.

2.2.1 Shadow Price Increases at the Rate of Discount:

At any time t the shadow price may be expressed as

$$P_t = P_0 \, e^{rt} \tag{13}$$

where P_0 = Shadow price at time 0

Substituting this expression in equation 4 and solving for a series of time dependent emissions provides the following results for CRAC,

$$CRAC = NPV \,/\, (\frac{1}{a} \textstyle\sum_0^{Te} C_t) \tag{14}$$

For this unique situation, the PCE term is reduced to 1/a, and the carbon term is not discounted. The computation of the NPV will still require the use of a discount rate appropriate to the project.

2.2.2 Shadow Price Increases Faster than the Rate of Discount:

In this case, at any time t the shadow price may be expressed as

$$P_t = P_0 \, e^{brt} \tag{15}$$

where b > 1

Substituting this expression in equation 4 and solving for a series of time dependent emissions provides the following results for CRAC[f],

$$\begin{aligned} CRAC &= NPV/(PCE \sum_0^{Te} C_t (\frac{1+br}{1+r})^t) \\ PCE &= \int_o^\infty e^{(br-r-a)t} \end{aligned} \tag{16}$$

2.3 Illustrative Example:

In order to illustrate the effect of different functional forms on the cost-effectiveness of projects, we compare the CRAC for two hypothetical projects which sequester the same amount of carbon (50 tons) at different times in the future. We will show that the project which sequesters carbon in the near future is more cost-effective to pursue when the future shadow price increases slower than the rate of discount and vice versa. Each project has the same net present value of monetizable benefits, and each has a 30 year life. For our example, we assume that the project incurs a net present cost of $1000. The carbon flows for Project 1 occur in the first five years, and those for Project 2 occur in the last five years of the 30 year project life (Figure 1). We assume an annual atmospheric carbon decay rate of 0.75%, which applies to both projects.

The cost of conserved carbon emissions (CCCE) for both projects is identical. A cost of $20 (1000/50) is incurred while sequestering one ton of carbon from each

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[f] The time series representing the PCE term diverges when br > (r+a). For numerical computation, we assume a very large value for infinity in order to arrive at a finite value for PCE.

Figure 1

Carbon Sequestered in Two Projects

Net Present Cost: $1000 for Each Project

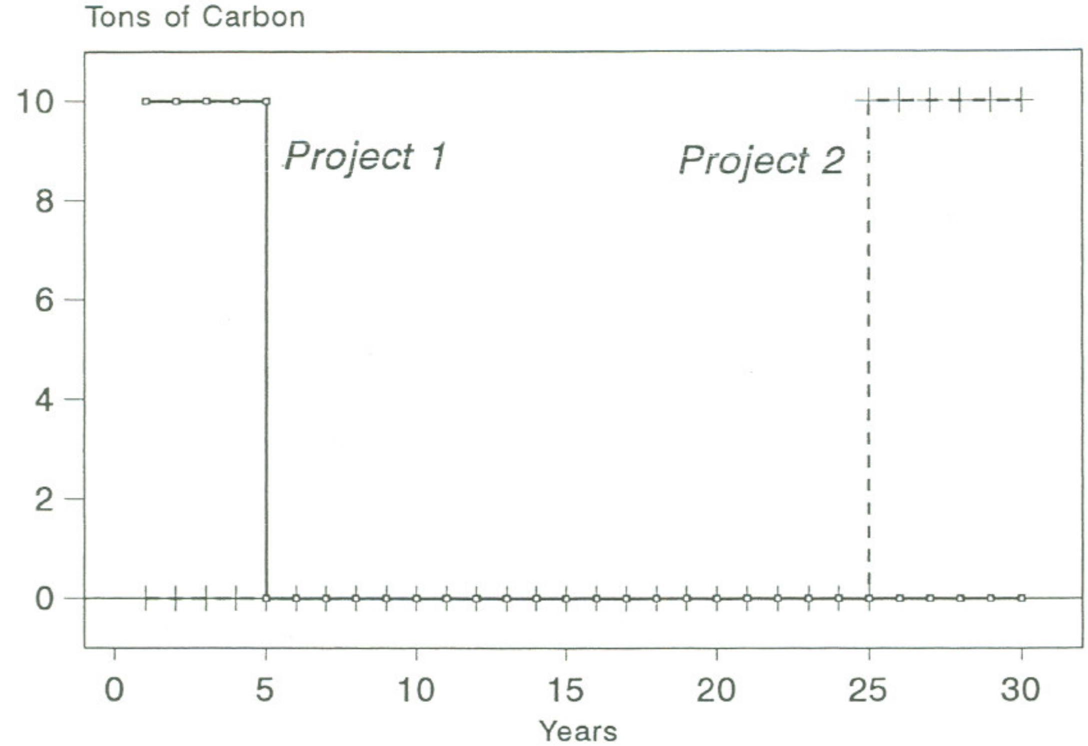
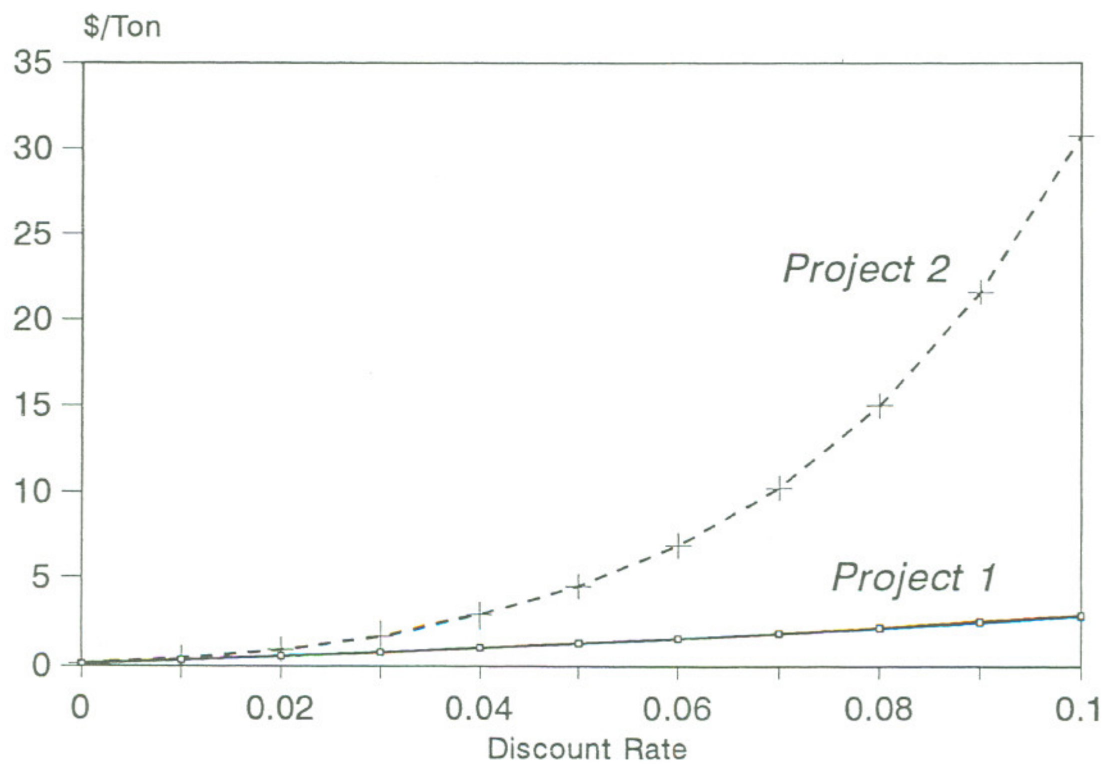


Figure 2

Cost of Reducing Atmospheric Carbon

Shadow Price Increases at Less than Discount Rate

(Constant Shadow Price Illustration)



project. Using this indicator, we would be indifferent to choosing among these two projects.

We derive the cost of reducing atmospheric carbon (CRAC) using three different functional forms for the future shadow price; 1) constant over time (increasing slower than the rate of discount), 2) increasing at the rate of discount, and 3) increasing faster than the rate of discount. Figures 2, 3 and 4 show the CRAC value for Cases 1, 2 and 3 respectively, when plotted against the discount rate.

For Case 1, the CRAC indicator is derived using equation 10. The CRAC value for Project 1 is lower than that for Project 2. For example, at a discount rate of 6%, Project 1 and 2 incur a cost of about \$2 and \$7 to sequester a unit of atmospheric carbon. Project 1 incurs a lower unit cost and clearly is to be preferred. The difference in the CRAC value between the two projects increases with the discount rate.

For Case 2, equation 14 is used to compute the CRAC indicator. Since the shadow price increases at the rate of discount, the CRAC value is identical for both projects, which means that we would be indifferent to choosing one project over another regardless of the discount rate. This also implies that the distribution of carbon flows over time does not affect the cost-effectiveness of projects. Similar to the CCCE indicator the CRAC value does not vary with the discount rate, but it is much smaller compared to the former.

For Case 3, equation 16 is used to compute the CRAC value. The shadow price increases 5% faster ($b = 1.05$) than the rate of discount. In this case, project 2 incurs a lower unit cost than project 1, and is more cost-effective.

2.4 Implications of the Atmospheric Carbon Approach:

The above example illustrates that project selection would depend on the functional form assumed for the shadow price, and its cost-effectiveness would depend on the rate used to discount the monetary implications of carbon flows.

When compared with the current approach to estimating cost-effectiveness (CCCE shown in equation 1), the CRAC value estimated using the three equations 10, 14 and 16 is much lower, and the two equations 10 and 16 yield a different ranking of projects. The denominator of each equation has two terms. The first term is the PCE, which will be the same for each project (but which varies with the discount and decay rate), and the second one, which represents the emissions discounted over the

Figure 3

Cost of Reducing Atmospheric Carbon

Shadow Price Increases at Discount Rate

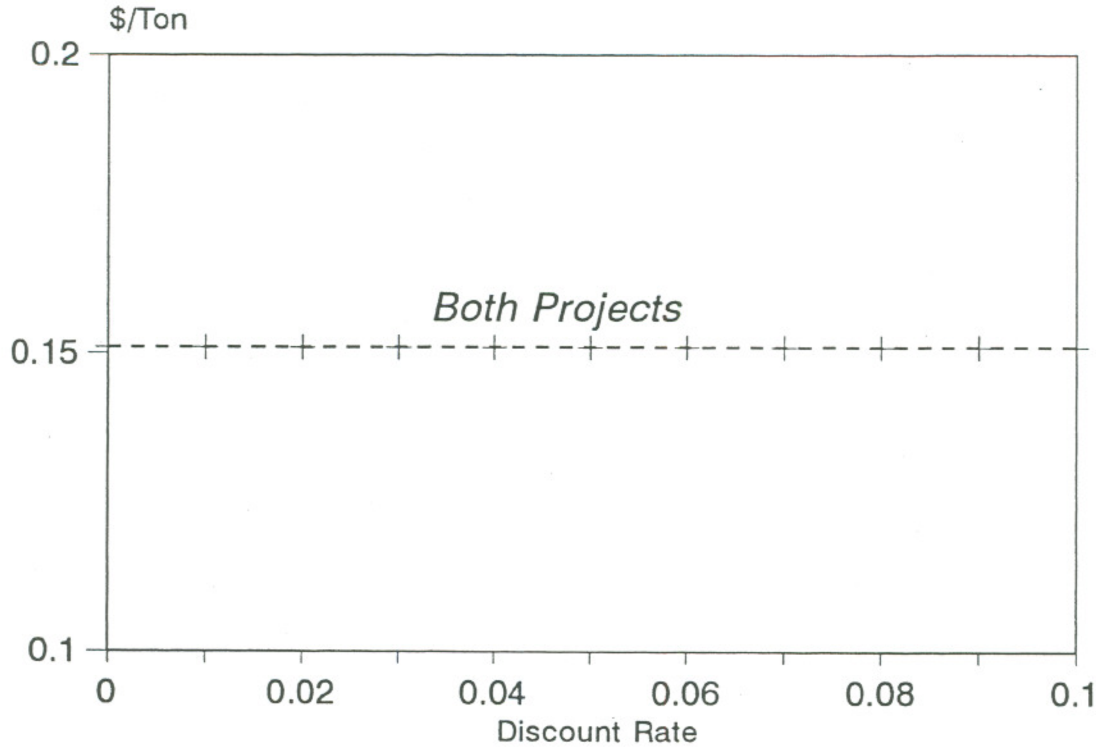
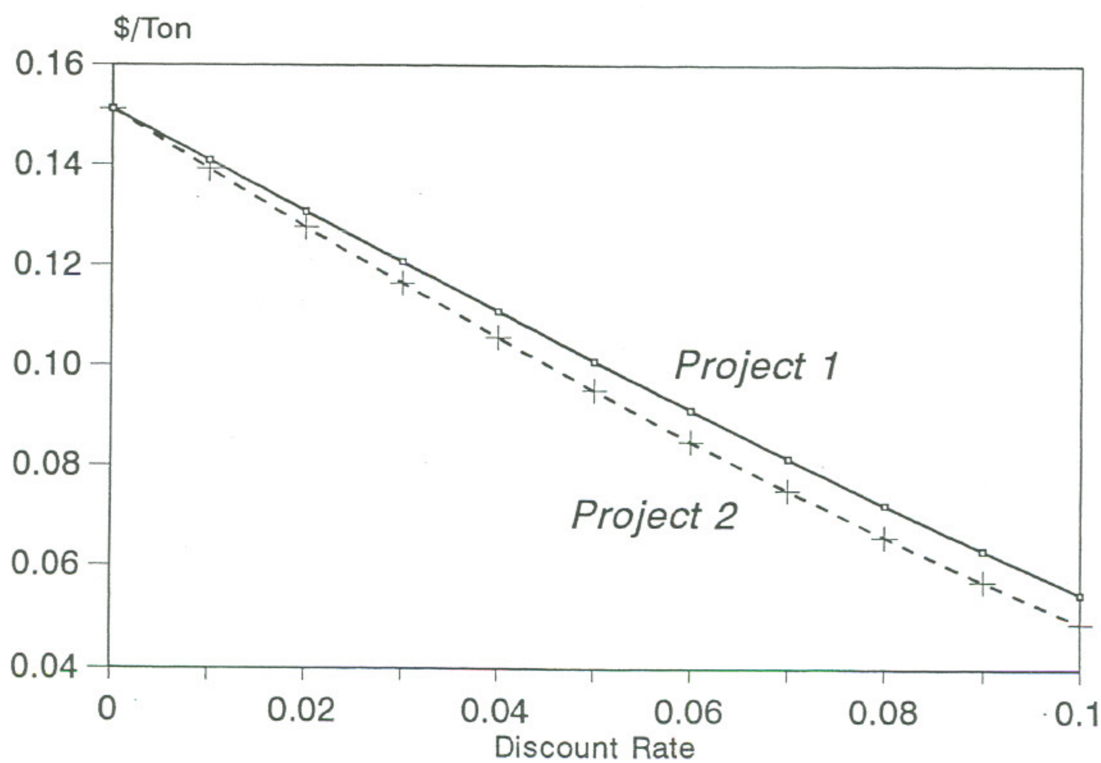


Figure 4

Cost of Reducing Atmospheric Carbon

Shadow Price Rises at 1.05% Discount Rate



project life to the present. The ranking of projects using equations 10 and 16 will be different to the extent the cumulative emissions are discounted. As we discuss later, the discount rate for the evaluation of carbon may be lower than that for monetary flows.

The present carbon equivalent (PCE) term reduces the unit cost indicated by CRAC compared to the CCCE for the same project. As our illustrative example shows, the value of CRAC is only 15 cents at a discount rate of zero compared to a CCCE of $20 per unit of carbon emissions This implies that the cost of a project to reduce carbon emissions goes a longer way towards reducing atmospheric carbon and its consequent damage. How much farther depends on the discount rate and the decay rate for atmospheric carbon.

The CRAC also indicates the price that project beneficiaries or the nation may be obligated to pay for eliminating a unit of emissions. However, they may not be willing to pay this price since the nation will experience only part of the damage caused by these emissions. The willingness to pay will depend on the perception of the extent of damage that a nation may have to bear. In absence of any international agreements, or lack of knowledge about the project's carbon impact on itself, a nation may be willing to pay little for carbon reduction or sequestration.

The choice of the shadow price functional form will also be influenced by a nation's perception of the damages that it might sustain. Low-lying countries may view a rapidly increasing shadow price to be appropriate to account for the damages that sea-level rise may cause. All other benefits and costs being equal, these countries would favor implementation of projects which reduce emissions than those countries that expect to sustain minimal damage. A low-lying country's willingness to pay has to be tempered by its ability to pay as well. So Bangladesh may not be able to pay for the damages it might sustain, but the Netherlands may be able to afford to reduce its perceived damages.

The sensitivity of CRAC to the future shadow price implies that the latter should be determined **prior** to the selection of projects. Under the Climate Convention, this would require that Parties to the Convention agree on how fast the shadow price is likely to change in the future. It is not necessary to determine the absolute damages that carbon might cause but only the rate at which they would change. Selection of projects would be guided by this functional form. Since the number and type of projects that are implemented will change the future shadow price, the determination of the future shadow price path will have to be an iterative process. The Parties may have to revisit the shadow price issue every so often in order to reevaluate the future shadow price path.

Determining the functional form is necessary for ranking projects, but it is inadequate to decide the number of projects which should be implemented. In order to decide this, some form of constraint on the carbon flows or the total funds to be invested in carbon reduction is needed.

For example, one type of constraint would be to limit the cumulative emissions between now and some future year, say 2010. Knowing the amount of emissions that need to be reduced between now and 2010, and the future shadow price, one can rank the available projects until the cumulative emissions are reduced to the desired level. If the shadow price were to increase faster than the discount rate, then projects that reduce emissions in 2010 would be favored. The ranking would begin with projects that reduce emissions in 2010 and work backwards until the cumulative emissions were reduced to the desired level.

All other costs and benefits being equal, our cost-effectiveness indicator would suggest that projects that sequester carbon in the future be ranked higher if the shadow price is expected to increase faster than the rate of discount. The implication is that if the shadow price is expected to increase then projects with identical net monetary benefits should be implemented such as to reduce carbon emissions in the future rather than today.

However, there is at least one reason which may compel a higher ranking for nearer term projects. In any time period, there is some probability of a catastrophic event occurring; in other words, of a very high shadow price. From the perspective of individuals who are risk averse, a very high shadow price in the near-term may be sufficient reason to pursue projects prior to the occurence of the catastrophic event. The ranking of projects may change with the perceived distribution of shadow price over time and the probabilistic distribution within a time period.

We have discussed the implementation of projects under three separate shadow price paths. It is plausible that the shadow price may change at different rates in the future. For example, Anderson and Williams (1993)[11] have discussed the possibility of the shadow price rising at the rate of discount until it equals the difference between the marginal cost of backstop technologies and fossil fuels (Case 2). Beyond this level, the shadow price would not increase (Case 1). This possibility may be viewed as a combination of Cases 2 and 1 discussed above. If the time horizon chosen for consideration is before the backstop technology is reached, then we may be indifferent to the timing of carbon reduction (Case 2). However, if the horizon includes the period beyond the backstop technology, then it is better to implement as many projects as possible prior to reaching the backstop technology. If project implementation proceeds under these rules, the backstop technology would always remain a mirage, useful as a target but never to be achieved.

2.5 Ranking When Shadow Price is Influenced by Project Implementation:

In deriving the equations in Sections 2.1 and 2.2, we assumed that the carbon flows from the project were too small to have a significant impact on the shadow price of carbon. However, one can justifiably argue that the sole reason to pursue projects is to reduce the additions to the atmospheric carbon stock, which, assuming costs of carbon reduction remain unchanged, would lower the future shadow price of carbon. Does this suggest that a large number of projects should be implemented as soon as possible?

The three illustrative cases analyzed above would suggest that carbon reduction be delayed as much as possible, if after the implemetation of such projects the shadow price is still expected to increase faster than the discount rate. Our analysis above would imply that given projects with identical monetary benefits, those that sequester larger quantities of carbon in the future be favored. On the other hand, the implementation of a large number of projects immediately would be cost-effective if these projects reduce future damage from carbon and flatten the cost (supply) curve to an extent where the shadow price rises slower than the rate of discount in the future. (The cost curve may get flatter because of the learning experience with technologies.)

There may be practical reasons to pursue projects today regardless of the shape of the future shadow price curve, such as the demonstration and learning effect of projects. In order to implement projects in 2010, it may be necessary to have a series of well designed projects ready for implementation.

3. Discount Rate

An important factor in the estimation of the shadow price and a project's cost-effectiveness is the discount rate. Much has been written about the estimation of discount rates for projects with long-term consequences.[12,13] In this section, we primarily address issues related to the choice of the rate for discounting carbon flows. Should it be different than that for the monetary flows? What factors influence the estimation of the discount rate? Does the rate vary with who pays for mitigating carbon impacts? We address these issues below.

The discount rate reflects the return on foregone present consumption that is sacrificed to secure future consumption. Since foregone present consumption is invested to secure future consumption, the discount rate is equal to the after-tax real rate of interest or return on capital investment.

For economic analysis of projects in the developing countries, real social discount rates between 8 and 12% are commonly used by the World Bank. We assume that the monetary benefits and costs of the project are borne by the nation in which the project is located. Using the rates set by the World Bank for each country would be a practical alternative for evaluating the present value of monetary costs and benefits for each project. We discuss some of the issues involved in selecting a discount rate, but a detailed discussion is beyond the scope of this paper.[9]

There are three different arguments which need to be considered in arriving at a discount rate for carbon flows. One is the global impact of carbon flows from a project located in one country, second is the declining rate of discount with rising income over a long time period and third is the concern for rights of future generations compared to those of the current one. We will show that each argument suggests that carbon be discounted at a lower rate than that used for monetary flows.

Evaluation of discount rates, which influence the denominator in equations 10 and 16, carries two different dimensions -- the global impact of emissions and their long residence time in the atmosphere. Emissions from a project located in one country will add to atmospheric carbon and impact all countries. Had there been a global authority to invest in carbon adaptation projects, then its discount rate would apply for valuing carbon emissions. This discount rate would be typically lower compared to that used by developing countries.

Since a global authority does not exist, the discount rate will depend on what type of agreements are drawn among the Parties to the Climate Convention to invest in projects worldwide. If no agreement exists, and each country has to take care of

[9] The correct discount rate to use for monetary evaluations has been debated at length. Lind (1982) provides an overview of the issues involved in the choice of discount rates for long-term energy projects. Cline (1992) provides a discussion of the empirical evidence showing lower discount rates for longer-term projects.

its own adaptation projects, then its discount rate would apply.[14,h] Emipirical observation of discount rates across countries suggests that the discount rate is lower for the richer countries. One possible conclusion from this observation is that society's discount rate declines as it becomes wealthier, and the value it attaches to current consumption declines. Using the above argument, a declining discount rate would be appropriate for the long period that carbon lasts in the atmosphere. Alternatively, a fixed average discount rate may be used, which would be lower than that used to value shorter-term monetary flows from a project.

An implication of the long duration of atmospheric carbon is that the potential extended impact may stretch over several generations. Norgaard and Howarth have shown through an overlapping generations model that there are many efficient allocations of resources, each with different rates of interest and other prices, depending on the distribution of resource rights across generations.[15,16] While most economists heretofore were trying to derive correct interest rates through efficiency reasoning, Norgaard and Howarth show how the interest rate is affected by distributive decisions that are beyond economic reasoning. The rate of interest is a function of how current generations protect the rights of future generations and the extent to which they transfer additional rights and take previously recognized rights away. Howarth and Norgaard show how the decision to protect future generations is a distributive decision that must be morally based, not an efficiency decision that can be derived from economic reasoning (see Appendix B for detailed discussion of this line of reasoning.)

By being aware that our actions may affect future generations, and that these broad moral questions must be addressed, the discount rate, and factor/product prices in general, should be determined by how the moral issues are resolved, not vice-versa (Howarth and Norgaard, 1992).[17] New economic techniques are needed to address both the geographic and temporal distributive issues of global change, and it will undoubtedly be some time before the economic profession and other relevant disciplines have experimented with and adopted new approaches.

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[h] The incremental cost of reducing carbon emissions would be evaluated at a rate equal to the social discount rate for each country. However, alternative opportunities for investment through a central facility, such as the Global Environment Facility (GEF), should be evaluated at its own discount rate. Given two alternative investments in different countries, the incremental cost would be estimated using each country's discount rate. GEF would then evaluate the incremental cost of reducing carbon emissions using a single rate to reflect its opportunity cost of capital.

While more elaborate techniques for carrying out climate change analyses are being developed, we recommend the following:

a. The monetizable costs should be discounted at the societal discount rate valid for the country where the project is located. While there is good reason to believe that interest rates will fall as we try to protect future generations, it is by no means clear how low they will go. The analysis could be undertaken at several rates of interest so that the sensitivity of alternative projects to the rate of interest can be better understood.

b. In order to assure future generations of climatic stability, the carbon flows should be discounted at a rate different from that used for the monetary evaluation. This rate should be lower than that used to value monetary flows, but unlike that for monetary flows, it may be the same for every project in any country. The exact rate to use will vary depending on whether current or future generations deserve prominence. On equity grounds, it may be argued that the rate should be zero. On efficiency grounds alone, the rate should be the same as that used to evaluate long-term investments.

Note that, under equity considerations, by not discounting greenhouse gases prevented, it appears that we are indifferent between protecting immediate progeny relative to later progeny. Clearly we are interested in protecting all progeny, but this can not be accomplished equally well with each possible approach. Some approaches will provide more immediate protection, others better later protection, but when looking at individual projects, no preference can be made for one over the other. As projects get underway, it will become clear from a global overview as to which time periods are receiving less protection and projects should be undertaken to fill in those gaps. In our approach, we are not considering the possibility that future generations may reverse the climate impacts or adapt to a changed climate.

4. Summary and Conclusions:

This paper proposes a conceptual framework for the evaluation of the benefits and costs of restraining the growth of carbon emissions from projects. The current approach to evaluating cost-effectiveness of projects estimates the cost of reducing cumulative carbon emissions (CCCE). In so doing, it ignores the timing of carbon reduction, and the extent to which this decreases the atmospheric stock of carbon.

In this paper, we propose a cost-effectiveness criterion, the cost of reducing atmospheric carbon (CRAC), which accounts for these two factors. We extend the conceptual framework to cover inert and reactive GHGs.

For the same project, the value of CRAC is much lower than that of the CCCE, implying that the project cost goes longer towards avoiding damage than implied by the CCCE. We illustrate that the CRAC value is sensitive to the shadow price of carbon. The ranking of projects using CRAC can change depending on the changes in shadow price over time. A shadow price increasing slower than the discount rate would favor projects in the near-term and vice versa.

The sensitivity of project ranking to changes in shadow price implies that projects cannot be selected with disregard to the future shadow price of carbon. In order to finance projects under the Climate Convention, Parties to the Convention need to agree on the functional form of the shadow price. It is not necessary to agree on the extent of damage that carbon might cause, but an agreement is necessary on the rate at which the damage will increase or decrease and the rate at which costs of mitigation technologies will change in the future. In addition, a constraint on the carbon emissions is necessary to decide how many projects will need to be implemented. Alternatively, a funding constraint may be used to decide the extent of emissions reductions that may be achievable.

It is unlikely that a developing country would adopt a project whose sole purpose is to sequester carbon. Projects with multiple benefits, including that of carbon sequestration or reduction, are likely to be viewed more favorably. In order to illustrate the value of these benefits, our framework uses the net present value of monetizable benefits, rather than the capital investment, to determine the CRAC.

We propose that the monetizable benefit be evaluated at a social discount rate appropriate to the country where the project is located, but that the carbon be discounted at a rate lower than the monetary one. Given our limited knowledge of atmospheric carbon and its impacts on future generations, a zero discount rate would be appropriate as well.

The paper thus provides a conceptual framework to determine the incremental cost of carbon reduction or sequestration. The framework provides a way to account for the economic discount and atmospheric GHG decay rates, alternative functional forms of the shadow price, residence period of carbon or other GHGs in the atmosphere, and multiple monetary benefits of projects. The last item is of particular importance to the developing countries.

APPENDIX A

Inert Gases:

Thus far we have discussed the shadow price indicator for carbon emissions. Below we describe the treatment of inert greenhouse gases, such as nitrous oxide. Each gas has been estimated to have a higher radiative forcing than carbon dioxide. Nitrous oxide is 100 times more potent than CO_2.

For the inert gases, we can define a present equivalent (PNE) similar to the PCE for a constant shadow price. PNE may be expressed as

$$PNE = \int_0^\infty e^{-(r+b)t}dt = 1/(r+b) \tag{17}$$

where PNE = Present inert gas equivalent
b = rate of inert gas decay in the atmosphere

Inert GHGs can be expressed in terms of their CO_2 equivalents by using an equivalent radiative forcing value. We assume that the radiative forcing of an inert gas is k times that for carbon dioxide.[i] With this modification, we can express the shadow price, P_{ghg}, in terms of the PCE and PNE.

$$P_{ghg} \geq NPV/(C_0\ (PCE + m\ k\ PNE)) - CRAGHG \tag{18}$$

where CRAGHG = Cost of Reducing Atmospheric GHG
NPV = Net present value of monetizable benefits
C_0 = Carbon emissions or sequestrations in initial period
PCE = Present Carbon Equivalent
PNE = Present Inert Gas Equivalent
k = Inert gas radiative forcing as a multiple of carbon
m = Inert gas emissions as a multiple of carbon

For a project with series of emissions of carbon and inert GHG gases, the shadow price is:

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[i] Radiative forcing is defined here as the energy absorption potential of an inert GHG molecule relative to that of carbon, without considering the residence time.

$$P_{ghg} \gtrsim NPV/(PGHGE \sum_0^{Te} C_t \, e^{-rt}(1+m_t)) - CRAGHG \tag{19}$$
$$PGHGE - PCE + k \, PNE$$

where PGHGE = Present GHG Equivalent

C_t = Carbon emissions or sequestrations in time t

P = Time period over which GHG emissions or sequestrations occur.

m_t = Inert gas emissions as a multiple of carbon dioxide emissions in time period t.

Reactive Gases:

For methane and carbon monoxide, gases which have short residence times and are converted to carbon dioxide, the present gas equivalent has to be computed differently. Over the average time for each gas, the treatment is similar to that described above for an inert gas. Beyond that period the gas converts to carbon dioxide. Thus it is important to account for the decay of methane over its residence period, say M years, and the decay of carbon dioxide from M to $M+T_r$ years.[j] Further, we assume that all the methane is converted to carbon dioxide. The present gas equivalent for methane may be described by

$$PGHGE - k \, PME + m \, e^{-M} \, PCE \tag{20}$$

where PME = Present Methane Equivalent

m = 2.65 or Methane conversion factor to CO_2

$$where \quad PME = (1 - e^{-(r+Y)M})/(r+Y) \tag{21}$$

where M = Average atmospheric time period for Methane

Y = Decay rate of methane

[j] We make two simplifying assumptions in this estimation. The first assumption is that carbon dioxide is formed at the end of the methane decay. This underestimates the warming during the period the methane is decaying to carbon dioxide. The second assumption is that methane is converted to carbon dioxide only. Methane could also react with other gases which would change the warming potentials and their present carbon equivalents.

The shadow price for methane release may be expressed as

$$P_{ghg} \geq NPV/(M_0\ PGHGE) - CRAM \tag{22}$$

where CRAM = Cost of Reducing Atmospheric Methane
M_0 = Initial methane emissions

For projects with a stream of annual methane emissions, the present equivalent of a string of methane releases combined with subsequent decay of carbon dioxide over a period of time is computed using the equation below. The shadow price may then be expressed as

$$P_{ghg} \geq NPV/(PME\sum_0^{Te} k\ C_t\ e^{-t} + mPCE\sum_M^{M+Te} C_t/\ ((1+r)^t(1+M)) - CRAM \tag{23}$$

where T_e = Period over which emissions or sequestrations occur

APPENDIX B

The key features of the Norgaard and Howarth model are illustrated in Figure A-1, following Bator (1957).[18] The x-axis is the utility of the current generation, the y-axis is the utility of each future generation, and the utility possibility frontier represents the tradeoff between current and future generations. Points along this frontier are determined by the distribution of resources, environmental services, and human-produced capital between generations. Each point on the utility frontier is efficient and, given the distribution of assets, would be maintained by a wholly different set of prices. The "socially optimal" trade-off is at the tangency with the social welfare function. Note that when this generation does more to assure assets for the next generation, the trade-off between generations, or the rate of interest, decreases. The social welfare function embodies broad social mores with respect to who is entitled to what. These mores then determine how the economy operates. Whatever values are expressed in the market place reflect these broader social mores, and when there is public debate over what those mores should be, values from the market place cannot resolve debate since market values stem from past moral choices.

Historically, economics has incorporated all of the issues summarized by Figure A-1. During the past three decades, however, neoclassical economics has emphasized efficiency. The emphasis has been on how to move the economy from a position inside of the utility frontier out to the frontier. Global climate change and biodiversity loss are forcing economics to once again acknowledge its links to moral philosophy (Howarth and Monahan, 1993). Before the 20th century, few asked whether future generations had a right to a climate approximately like that of today or whether they had rights to biodiversity because the vast majority of people presumed that these were intransigent. Now that we are aware that our actions may affect future generations, and that these broad moral questions must be addressed. The discount rate, prices in general, should be determined by how this broad moral question is resolved, not vice versa (Howarth and Norgaard, 1992).

At the same time, scientists would like to help the public choose between specific options with the general moral choice they face. Given the increasing acceptance of the broad moral choice to protect future generations from climate change, how do we choose between specific options to do so. The question now is how we should "best" respond, what mix of resources, environmental services, and human-produced assets would best protect future generations? How can scientists facilitate making specific decisions about specific resources given that interest rates and prices, as shown in the abstraction of Figure A-1, are going to depend on very

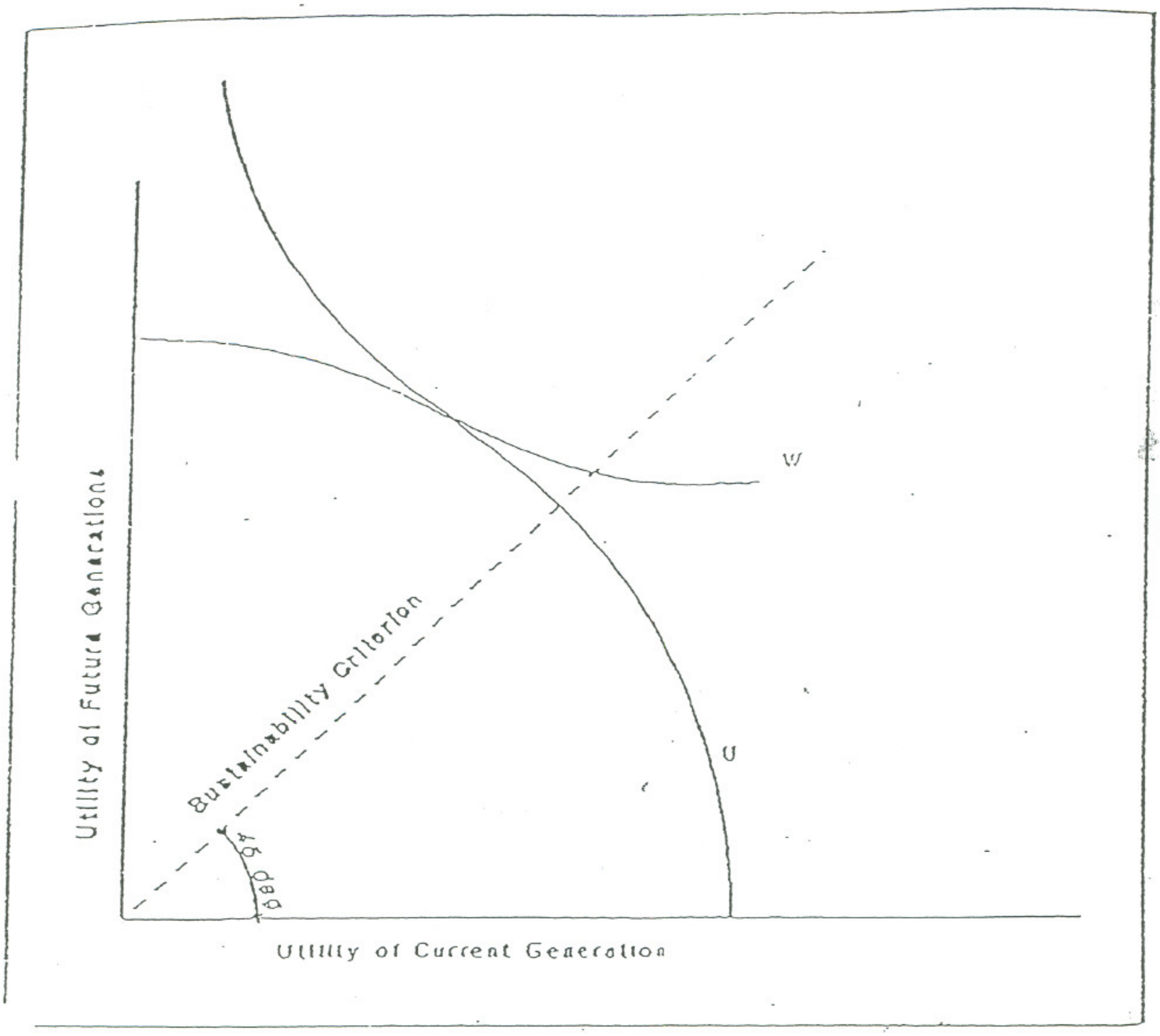

Figure A-1. A utility possibility frontier between generations with a social welfare and a sustainability criterion.

broad decisions? Making specific decisions requires assuming something about the "rest of the world." *Ceteris paribus*, assuming everything else the same, has been the normal assumption of economic analysis heretofore. It allows the analyst to use existing (corrected) prices and interest rates. *Ceteris paribus* has made sense historically because, even though different parts of the economy have always been changing, at least they were not all changing in response to the same driving factor affecting the specific decision under consideration. *Ceteris paribus* hardly makes sense when confronting the specifics of global change.

We need a new assumption, let's call it *ceteris mutandis*, meaning everything changing in response to a single phenomena. In the case of global climate change, the single phenomena would be the broad decision to protect the climate rights of future generations even while this broad decision will be carried out through a myriad of smaller decisions. Overall, however, we can expect this additional care for the future to result in a decrease in interest rates. Ideally, *ceteris mutandis* could be broadly simulated with dynamic general equilibrium models in order to see how key types of prices would shift, and then these prices could be used to make more specific decisions between specific options. The process might best be iterated since as more is learned about specific options, it might be appropriate to modify the general equilibrium model. New economic techniques are needed to address issues of global change, and it will undoubtedly be some time before the economics profession with the help of others has experimented with and adopted new approaches.

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